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EXCAVATION AND SUPPORTED SOLUTIONS FOR THE UNEXPECTED FAILURE CONDITIONS AT SYMVOLO MOUNTAIN TUNNEL CONSTRUCTION

CHATZIANGELOU M, THOMOPOULOS ACH & CHRISTARAS B

Department of Geology, Aristotle University of Thessaloniki, Thessaloniki, Greece

ABSTRACT

The tunnel of Symvolo Mountain, which is 1160m long, is placed on South-west of Kavala City at Northern Greece. The tunnel consists of two bores with NW-SE direction, which are connected by two small tunnels. The variety of rock mass quality, the presence of opened faults, and the aquifer's location above the excavation, minimize the stability of rock mass during the excavation and temporary support works.

The aim of the present paper is the description of the dangerous geological status of Symvolo Mountain and the proposed excavation solutions for managing the unexpected failure conditions.

For the above reasons, the sudden changes of the rock mass quality along the tunnel excavation are described. The causes of the geological failures are investigated and the failures are classified. Furthermore, the efficacy of support measures is tested and a relationship between the apparent face of wedges and the shotcrete thickness is proposed.

KEYWORDS: Anchors, Bolts, Shotcrete, Support Measures, Swellex, Tunnels

INTRODUCTION

The tunnel of Symbol Mountain is geotechnical located on Rodope mass. The excavation of the tunnel passes through alternations of gneiss, schists and marbles. The quality of the rock formations often changes from sound to weathered. It is, usually, heavily jointed and in many cases is folded. Furthermore, the presence of chloritic schist, lengthen 400m, causes numerous unexpected failures and support problems.

So, the excavation needed to be extremely careful, and for this reason a combination of excavation methods were used. The presences of an opened vertical fault, which is just placed at the exit of the tunnel and creates a shear zone about 400m long, increases the stability problems.

The water table is placed above the tunnel. The presence of water was taking into account during the excavations and support techniques (Anagnostou, 2006).

ROCK MASS QUALITY

At the beginning of the tunnel, the rock mass consists of fair quality gneiss with pegmatite veins, although there is a part of the tunnel between ch.36+300 – ch.36+400 where the quality of a part of gneiss is very poor. Walking along the tunnel, the rock mass quality becomes poor and very poor near the schist formation. At the middle of the tunnel (ch.35+800 – ch.36+300), there is a fair quality lens of marble. Walking to the outlet of the tunnel, we meet alternations of gneiss and marble medium and poor qualified. Between ch. 36+500 and ch. 36+700, there is a formation of chloriticschistolite of poor quality. That geological formation caused numerous problems during the excavation, as it was weathered very quickly after it was excavated. The last part of the tunnel is placed along a shear zone of an opened vertical fault 15/70 Figure 2.

EXCAVATION METHODS

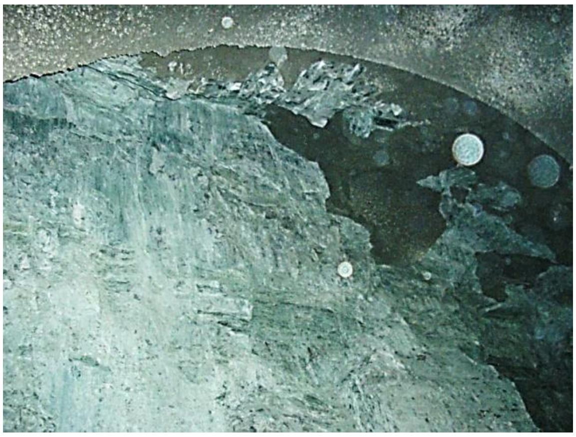


Figure 1: Chloritic Schist Rock Mass during Tunneling of Symbol Mountain at Strymonas-Kavala's Part of Egnatia Highway at Northern Greece

The rock mass along the tunnel differs from one place to another. Hard gneiss rock fair qualified, marble and granite alternate with fracture and deformed rock mass of gneiss and marble. Furthermore, the presence of chloriticschist and the shear zone, minimize the safety of the excavation. So, in order to excavate the tunnel safety, we ought to apply different excavated methods, taking into account rock mass behavior (Hoek & Karzulovic, 2000).

Near the outlets and where the rock mass is very poor, the tunnel was excavated mechanically, using the NATM method of excavation (Karakus & Fowell, 2004). The use of explosive measures was preferred on poor and fair quality of hard rock mass. The excavation of the chloritic schist and the shear zone is very dangerous. Although the chloritic schist is very hard and it is very difficult to be excavated with mechanical means, it is weathered very quickly, when it is in conduct with the atmosphere.

So, during the excavation of the tunnel, before the removal of excavation material to be completed, pieces of chloritic schist were felled down. The SCL method of the excavation (Thomas et al, 2004) was preferred on that case in order to support small parts of the face before the excavation be completed (Spyridis et al, 2013). Furthermore, light explosion was used in order to crack the hard rock mass helping the excavation Figure 1.

The sudden change of rock mass quality creates the necessity of fore polling (Kontothanassis et al, 2005).

Tunnel Stability

The sliding along a plane, the décollement from the roof and the fall of wedges (Chatziangelouet all, 2001) are the common failure causes. Sliding takes place along a tectonic surface from the walls of the tunnel. On the other hand, the décollement of a plate is due to its smooth surface in addition with the influence of gravity Table 1.

One hundred and eleven wedges are measured along the tunnel Table 2. All the wedges are to be collapsed, so the calculated safety factor, before the application of support is zero. From ch.36+139, 41 to ch. 36+176,22 a wedge with volume of 19244,17m^3 had been observed on the upper right part of the tunnel. The failure of that wedge can cause the collapse or all the overlying formations up to the surface. That wedge does not take into account on our estimations. Another one big wedge, with volume of 4390, 22 m^3 (from ch.36+215,595 to ch.36+240,379), which is also formed on the upper right part of the tunnel does not take into account on our estimations.

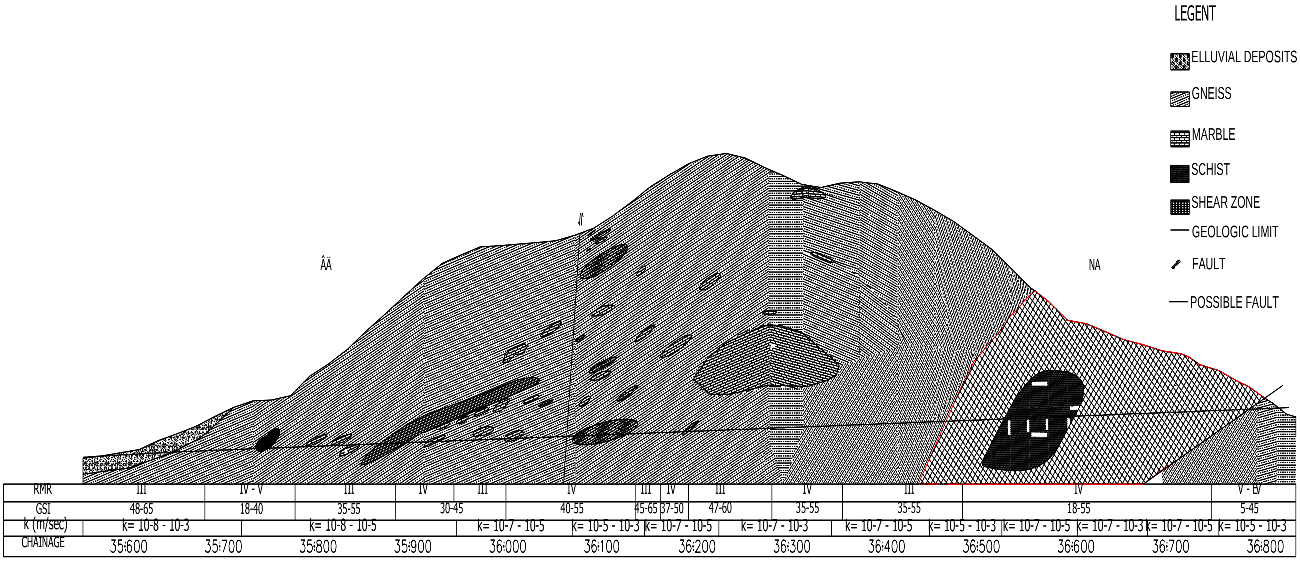


Figure 2: Geological Section along the Right Bore of the Tunnel

Table 1: Slidings and Dècollemens along the Tunnel

Chainage	Geologicalformations	Sliding	Dècollement	J1	J2	J3	J4	J5
35677,1 - 35680,70	Gneisswithpegmatiticintercalations	239/38 S		173/38 S	239/38 S			
35684,3 - 35695,10	Gneisswithpegmatiticintercalations	235/54 F		235/54 F	360/32 S			
35697,5 - 35706	Gneisswithpegmatiticintercalations	224/58		224/58	146/4 S	174/72	145/38	
35716,5 - 35724	Gneisswithpegmatiticintercalations	249/41, 153/67		153/67	249/41	100/6 S		
35728,8 - 35733,3	Gneisswithpegmatiticintercalations	308/59, 212/47		212/47	308/59	97/12 S		
35733,3 - 35741,4	Gneiss with pegmatitic intercalations and schist	272/54		33/18 S	206/46	272/54		
35741,9 - 35744,7	Schist	71/51		343/19 S	71/51	119/31		
35744,7 - 35749,4	Schist and gneiss with pegmatitic intercalations	31/73, 238/45 S		154/25	238/45 S	20/18	31/73	
35749,4 - 35765,2	Gneisswithpegmatiticintercalations	64/53, 275/52		275/52	344/30 S	64/53		
35765,2 - 35774,2	Gneiss with pegmatitic intercalations and schist	285/63 F		181/26 F	285/63 F	339/28 S	56/65	
35774,4 - 35776	Gneissandschist	226/46		226/46	351/18 S			
35776 - 35785	Marbleandgneiss	238/61		174/69	238/61	4/12 S		
35785 - 35790,4	Gneiss	252/59		252/59	110/79	8/22 S		
35790,4 - 35802,9	Marbleandgneiss	204/65	161/77	161/77	204/65	247/31	5/30 S	
35802,9 - 35864,4	Gneiss	54/60 S		54/60 S	243/43	10/24F		
35864,4 - 35880	Gneissandmarble	275/40 S, 71/77	Flow of weathered material, fall of soiled material	71/77	275/40 S	65/41	150/15 S	200/75

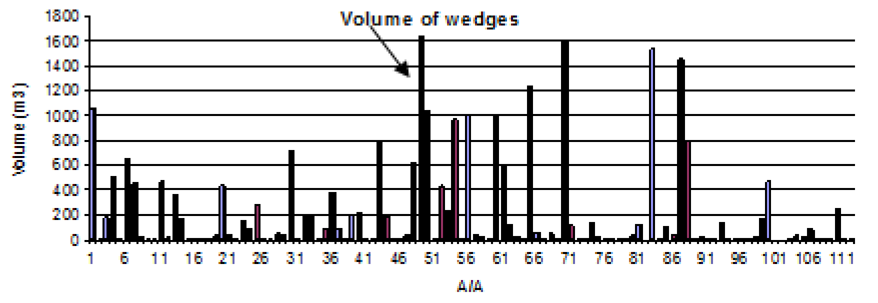
Table 1: Contd.,

35880 - 35882	Marble	100/64	Soilmaterial	258/29 F	358/68	100/64		
35882 - 35906,6	Gneiss and marble and chlorite	112/63, 175/67, 9/62 S	Soilmaterial	237/34 F	9/62 S	112/63	175/67	
35906,6 - 35934,626	Marble	204/62 F		155/64	204/62 F	258/19 S		
35934,626 - 35941,635	Gneiss, marble, pegmatite and quarzite	55/62, 198/72	283/12 S	55/62	198/72	250/70	283/12 S	
35941,63535948,349	Marble	66/56		100/68	66/56	288/8 S		
35948,349 - 35957,379	Gneissandmar ble	191/62, 313/36 S	313/36 S	313/36 S	191/60			
36008,125 - 36082,468	Gneissandmar ble	34/73, 267/29 S	267/29 S	267/29 S	151/60	34/73		
36082,468 - 36114,909	Marble	191/59, 270/58	318/16 S	66/88	191/59	270/58	318/16 S	
36114,909 - 36124,729	Marble	310/5 S		240/38	310/5 S			
36134,729 - 36139,41	Marbleandschi stolite	254/64, 349/26 S		254/64	349/26 S			
36139,41 - 36176,222	Marble	224/60, 33/68	348/13 F	224/60	140/68	33/68	348/13 F	
36176,222 - 36188,494	Marbleandgne iss	65/67		240/71	312/33 S	65/67		
36188,494 - 36240,379	Gneiss	310/11 S, 43/78, 233/66	310/11 S	233/66	332/68	43/78	310/11 S	
36240,379 - 36312,44	Gneissandmar ble	224/72		224/72	247/3 F			
36312,44 - 36+327,74	Gneissandmar ble	210/37	10/10 S	210/37	10/10 S			
36327,74 - 36350,746	Gneissandmar ble		358/22 S	232/43	152/32 F	358/22 S		
36425,28 - 36387,1	Gneiss	137/52 S, 227/78	19/27 S, 137/52 S	227/78	137/52 S	238/39	19/27 S	
36387,1-36481,783	Chloriticschist andgneiss	123/70 S		123/70 S				
36481,783 - 36443,87	Gneiss	80/55, 197/55 F		197/55 F	80/55	03 / 015 S		
36443,87 - 36499,58	Chloriticschist andgneiss	221/72, 26/74		221/72	26/74	137/16 S	147/60	
36499,58 - 36537,046	Chloriticschist	219/72	crackedmater ial, 138/44 S	219/72	212/11 S	138/44 S	04/016 S	
36537,46 - 36659,4	Gneiss	28/75, 149/74, 252/74	155/20 S, crackedmater ial	246/74	155/20 S	149/74	28/75	
36659,4 - 36717,5	Gneissandgran ite	220/63, 135/37		135/37	220/63	49/75	267/6 S	
36717,5 - 36740,9	Gneissandmar ble	30/58 S, 120/70		140/52	265/82	30/58 S		
36+740,9 - 36746	Gneiss	38/85		61/15 S	333/90	38/85		
36746 - 36749	Melange of granite, gneiss and marble	221/59, 128/68 F		128/68 F	221/59			
36749 - 36763,1	Graniteandkao linite	117/70 F		48/16 S	117/70 F	210/19	26/84	
36765,73 - 36766,7	Gneiss	15/60 F		45/84	348/38 S	108/46 S	158/60 F	
36766,7 - 36771,5	Gneiss	132/74 F, 117/43 S		132/74 F	117/43 S			
36771,5 - 36777,5	Gneiss	100/43		90/10 S	100/43			
36777,5 - 36779,5	Gneissandmar ble	124/40 S		188/70 F	287/63	35/63	120/70 F	124/40 S
36779,5 - 36789	Gneiss			36/83	81/89	153/68 S	171/36	

Table 2: Geometrical Characteristics of Most Important Wedges along the Tunnel of Symvolo Mountain

Chainage	Geologicalformations	Distance of the roof from the surface (m)	J1	J2	J3	J4	J5	Typeoffailure	Positionofthewedge	F.S.	Volume (m3)	Weight (tns)	z-length (m)	Apparentface (m2)	Height (m)
35675,9 - 35677,10	Gneiss	0	300/49	166/43	40/20			Collapse	Upperleftwedge	0	201,825	544,928	20,26	72,54	9,53
								Collapse	Lowerright wedge	0	208,672	563,414	16,12	66,51	9,85
35698,8 - 35707,2	Gneisswithpegmatiticintercalations	15	224/58	146/4 S	174/72	145/38		Collapse	Upperleftwedge	0	778,222	2101,198	40,39	210,56	12,68
								Collapse	Upperright wedge	0	187,967	507,51	13,17	80,02	8,66
35707,2 - 35710,1	Gneissandgranite	15	158/48	226/52	80/5 S			Collapse	Upperleftwedge	0	620,66	1675,781	45,56	221,48	9,34
35710,1 - 35718	Gneisswithpegmatiticintercalations	15	146/46	199/13 S	236/53	330/58		Collapse	Upperleftwedge	0	1646,741	446,2	40,72	276,07	22,14
								Collapse	Upperright wedge	0	1036,954	2799,776	18,51	121,47	35,26
35718 - 35725,8	Gneisswithpegmatiticintercalations	15	153/67	249/41	100/6 S			Collapse	Upperleftwedge	0	428,827	1157,833	25,85	124,25	11,71
35725,8 - 35730,3	Gneisswithpegmatiticintercalations	15	234/32	108/17 S	350/58			Collapse	Upperleftwedge	0	232,963	629	23,27	99,42	7,5
35730,3 - 35734,8	Gneisswithpegmatiticintercalations	15	212/47	308/59	97/12 S			Collapse	Upperleftwedge	0	967,241	2611,551	59,67	326,68	9,71
35734,8 - 35742,9	Gneiss with pegmatitic intercalations and schist	18	33/18 S	206/46	272/54			Collapse	Upperleftwedge	0	1004,184	2711,296	147,98	577,23	6,4
35746,2 - 35749,4	Gneiss with pegmatitic intercalations and schist	18	154/25	238/45 S	20/18	31/73		Collapse	Upperright wedge	0	1009,331	2725,194	26,31	141,8	22,61
								Collapse	Lowerright wedge	0	591,184	1596,196	23,67	112,33	18,47
35768,8 - 35774,2	Gneiss with pegmatitic intercalations and schist	34	181/26 F	285/63 F	339/28 S	56/65		Collapse	Upperright wedge	0	1236,274	3337,941	15	108,57	38,52
35792,5 - 35802,9	Gneissandmarble	22	161/77	204/65	247/31	5/30 S		Collapse	Upperleftwedge	0	1596,816	4311,403	31,37	212,72	26,18
								Collapse	Roofwedge	0	109,254	294,986	26,56	69,1	5,41
35908,4 - 35934,626	Marble	85	155/64	204/62 F	258/19 S	35908,4 - 35934,626		Collapse	Upperleftwedge	0	1539,353	4156,252	59,53	422,28	14,27
35934,626 - 35948,349	Gneiss, marble, pegmatite, quarzite	105	55/62	198/72	250/70	283/12 S		Collapse	Upperright wedge	0	1449,127	3912,462	17,44	118,23	41,21
35948,349 - 35955,63	Marble	105	100/68	66/56	288/8 S			Collapse	Upperright wedge	0	786,449	2123,411	49,36	269,86	9,69
36144,19 - 36188,494	Marble	158	224/60	140/68	33/68	348/13 F		Collapse	Upperright wedge	0	19244,169	51959,257	36,12	274,99	237,49
36215,595 - 36240,379	Gneiss	170	233/66	332/68	43/78	310/11 S		Collapse	Roofwedge	0	243,995	658,786	40,22	91,62	9,02
								Collapse	Upperright wedge	0	4390,322	11853,87	34,02	262,22	57,48
36350,746 - 36425,28	Gneiss	130	227/78	137/52 S	238/39	19/27 S		Collapse	Upperright wedge	0	370,929	1001,508	71,82	178,32	7,11
36481,783 - 36529,937	Chloriticschistandgneiss	99	221/72	26/74	137/16 S	147/60		Collapse	Roofwedge	0	704,133	1901,158	41,42	214,13	11,69
36359,4 - 36717,5	Gneissandchloriticschist	32	246/74	155/20 S	149/74	28/75		Collapse	Roofwedge	0	280,457	757,235	15,51	86,46	11,72
36717,5- 36740,9	Gneissandgranite	26	135/37	220/63	49/75	267/6 S		Collapse	Uperleftwedge	0	435,204	1175,05	32,9	129,55	12,59
36749 - 36763,1	Graniteandkaolinite	20	48/16 S	117/70 F	210/19	26/84		Collapse	Lowerright wedge	0	467,882	1263,282	105,6	295,25	4,95
								Collapse	Upperleftwedge	0	362,944	980,039	38,51	207,03	6,21
36765,73 - 36766,7	Gneiss	15	45/84	348/38 S	108/46 S	158/60 F		Collapse	Roofwedge	0	451,866	1220,39	14,83	57,62	26,9
36777,5 - 36781,9	Gneissandmarble	8	188/70 F	287/63	35/63	120/70 F		Collapse	Roofwedge	0	506,556	1367,7	20,86	124,35	13,8
								Collapse	Upperright wedge	0	659,163	1779,739	8,3	31,97	67,29
36+781,9 - 36789	Gneiss	7	36/83	81/89	153/68 S	171/36		Collapse		0	1057,986	2856,561	21,09	182,01	28,21

Usually, there is a relation between the weight and the volume of the wedges. It is common place, the wedges with big volume to be also heavy. But an exception of the above, is observed between ch.35+710 and ch.35+716,5, where there is a wedge with the one of the biggest volumes (1646,741 m^3), but one of the slightest ones (weighted 446,2 tns) Figure 3. That is due to the very poor quality of the rock mass, in addition to fracture and deformation. The deformation reduces the apparent weight of the rock mass. Also, the numerous of discontinuities, as they are crossed, they cause empty space at the cross point, so the weight of the wedge does not increase so much as the volume increase.



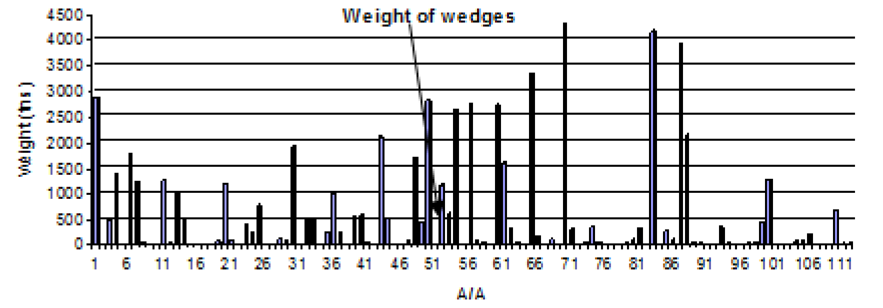


Figure 3: Comparison between Volume and Weight of Wedges. The Arrow Shows the Position of Wedge with Volume of 1646, 741m^3, and Weight of 446, 2 tns

COMPARING DIFFERENT SUPPORT MEASURES

The rock mass quality methods, RMR (Bieniawski, 1989) and GSI (Hoek, 1994), are used for determining the efficacious support measures of the slopes and the tunnels in the area (Christaras et al, 2002). According to the geotechnical characteristics of the rock mass, a combination with different support measures is used. The present paper examines the effectiveness of different types of anchors and shotcrete on the rock mass of Symvolo Unit. For this purpose, the support of the tunnel is tested using mechanical anchors 6m long, swellex 3m long, grouted anchors 3m long with 50% bond length, grouted anchors 3m long with 100% bond length and shotcrete with thickness of 5cm Figure 4. Actually, the wedges aretested being supported by the above measures using them separately one another. The required safety factor which is used for comparisons is 1,5.

Twenty five wedges are observed to be supported with mechanical anchors with length of 6m. Five wedges are supported with swellexbolts (William et al, 2001). So, the mechanical anchors can support more wedges than the swellex bolt can. Also, there is no difference when the bolts are grouted at 50% of their length and are totally not grouted. The safety becomes bigger when the bolts are totally grouted. Forty seven wedges are supported sufficiently.

Also, comparing the safety factors, the grouted anchors with 100% bond length (Shugi et al, 2013) increase

the safety more than the grouted anchors with 50% bond length. The percent of safety increases two times with the use of grouted anchors with 10% bond length. Also, shotcrete application can support effectively the majority of wedges even then the applied shotcrete is very thick, considering, seventy four wedges, from one hundred and three, are supported effectively with shotcrete 5cm thick Figure 4.

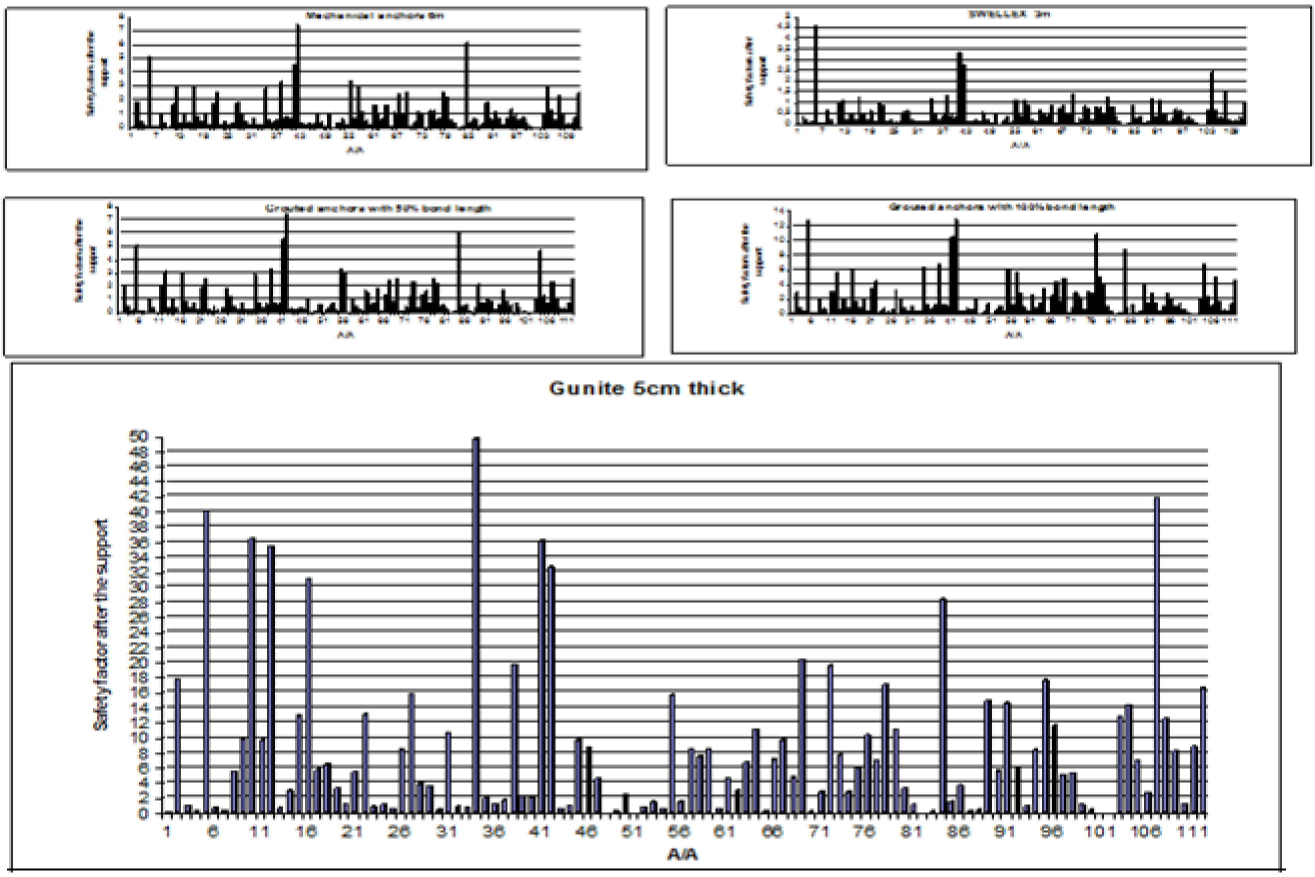


Figure 4: Safety Factors of the Wedges after the Support of Different Measures

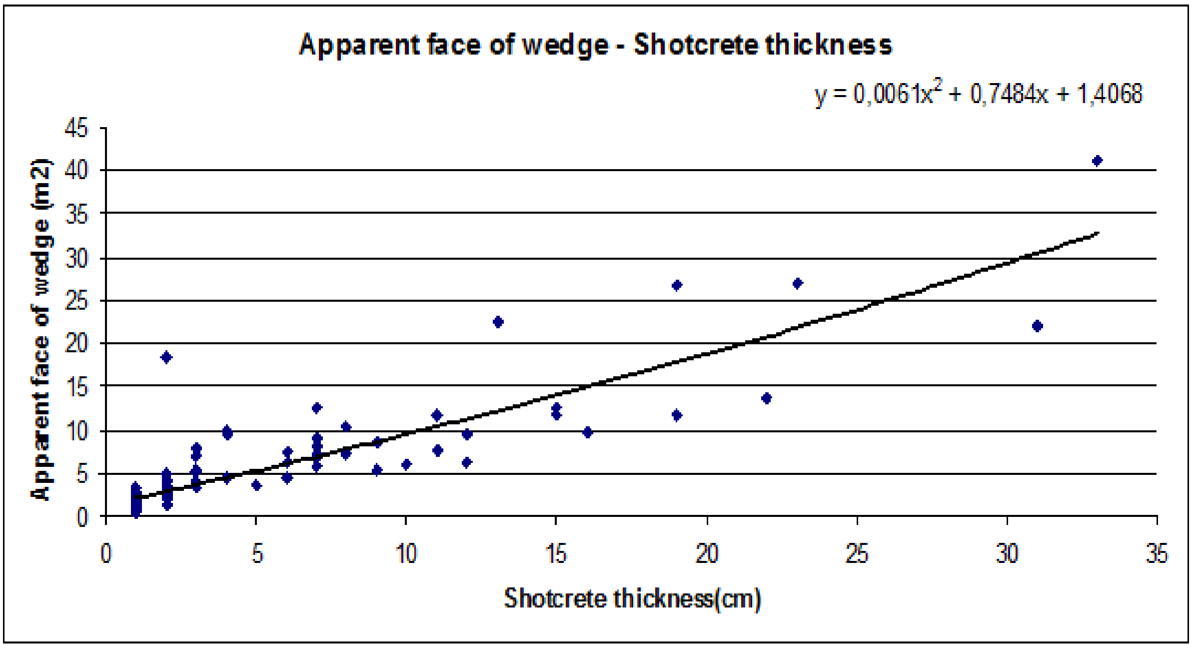


Figure 5: Relationship between Apparent Face of Wedge and Shotcrete Thickness

CALCULATION OF SHOTCRETE THICKNESS USING THE APPARENT FACE OF WEDGE

As the excavation of tunnels and the application of the support measures are dangerous, the quick calculation of shotcrete thickness during the excavation is useful. Comparing the apparent face to the wedges (the surface which is appeared at the inner surface of the tunnel) with the demanded shotcrete thickness (thinner than 40cm), in order the unstable wedges to be supported, a relationship is resulted Figure 5;

$$F\ (m^2) = 0,\ 0061 * [h\ (cm)]^2 + 0,7484 * h(cm) + 1,4068 \quad (1)$$

Where h = shotcrete thickness (cm)

F = apparent face of the wedge (m^2)

The coefficient of the above relationship is calculated 0,877.

The above relationship has the same form with the relationship, which has calculated from the data of Asprovalta tunnels of Egnatia Highway (Chatziangelou, 2008);

$$F\ (m^2) = 0,\ 3489 * [h\ (cm)]^2 + 16,654 * h(cm) + 14,049 \quad (2)$$

Asprovalta tunnels are located at Serbomakedonian mass and the tunnels are passed through gneiss with pegmatitic intercalations, marble and amphibolite. The coefficient of that relationship is calculated 0,082.

CONCLUSIONS – RESULTS

The tunnel which crosses the Symvolo Mountain was excavated dangerously because of the difficult geological status with unexpected failure conditions. The sliding along a plane, the “décollement” from the roof and the fall of wedges are the common failure causes.

Different methods were used in order to excavate the tunnel safety. The NATM method of excavation was used near to the outlets and where the rock mass is very poor. On poor and fair quality of hard rock mass the explosive measures are the most effective. Also, light explosion was used in order to crack the hard rock mass helping the excavation. Chloritic schist formation and the places, where the loose deformed material flows from the walls and the face, were excavated by the SCL method.

By Studying the geometrical characteristics of wedges, we conclude that the weight reduce of the wedges with big volume is due to i)deformation which reduces the apparent weight of the rock mass and ii) the cross of the numerous discontinuities, that they cause empty space at the cross point.

Examining the effectiveness of different types of anchors and shotcrete, we conclude that the mechanical anchors can support more wedges than the swellex bolts can. Also, there is no difference when the bolts are grouted at 50% of their length and are totally not grouted. The safety becomes bigger when the bolts are totally grouted. As far as shotcrete concern, more than 50% of wedges are supported effectively with shotcrete 5cm thick.

Finally, comparing the apparent face of the wedges with the demanded shotcrete thickness (thinner than 40cm), a relationship (1) is resulted in order the unsteady wedges to be supported. The above relationship has the same forma with the relationship (2), which has calculated from the data of Asprovalta tunnels of Egnatia Highway;

Consequently, there is a relation between apparent face of the wedges and the demandedshotcrete thickness being formed;

$$Y = a*x^2 + b*x + c \quad (3)$$

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